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K. Ya. Kondrat'yev, N. F. Romanteyev,
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# THE USE OF THE AIRGLOW LAYER EFFECT FOR AUTONOMOUS NAVIGATION AND ORIENTATION OF MANNED SPACECRAFT

K. Ya. Kondrat'yev, N. F. Romanteyev,
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ABSTRACT. The airglow layer observed by the spacecraft Soyuz 5 is described. The use of the airglow layer for navigational purposes is postulated on the basis of Soyuz 5, Soyuz 9, and rocket measurements.

The use of the celestial horizon has been suggested as a possible point of reference for autonomous navigation and orientation in flights around the earth [1]. The results of observations made from on board spacecraft show, however, that the earth's daytime horizon is obscured by optical haze, and that the twilight horizon cannot always be fixed sharply because of cloudiness [2-7]. This paper will describe the observation of the airglow layer on the night side of the earth during the flight of the Soyuz 5 spacecraft on 15 January 1969. The existence of a quite sharp, stable, upper boundary of this layer leads to the postulation that it can be used for navigating and orienting spacecraft during flights in circumterrestrial orbits. /1278*

An ash gray airglow layer was observed above the night horizon along an arc within angles A = 80° to 280° (from the bearing to the sun) when Soyuz 5 was in the earth's shadow. The upper boundary of this layer was slightly obscured, but was sharp enough for it to be distinguished by the naked eye. Narrow, brighter bands of light were observed near the earth's geographic horizon, and at the upper boundary of the ashen airglow layer. Visible brightness diminished in the center of the ashy layer and remained constant.

Stars were seen as points of light without diverging rays (while the observer was in the earth's shadow), and it was easy to identify the constellations, particularly Ursa Major, Cassiopeia, Auriga, the Southern Cross, and others. Once a star begins to set below the geographic horizon it does so quite definitely, and disappears rapidly. The tangency between the star and the upper edge of the

* Numbers in the margin indicate pagination in the foreign text.

of the airglow layer can be fixed with an accuracy of about 1 second because of the spread in its boundary. When a star passes through the ashen airglow layer its color changes from whitish to yellowish, and its brightness diminishes by a factor of approximately 2 to 2.5, remaining constant within the layer. This is indicative of the homogeneity of the brightness structure of the ashen layer in the vertical direction (with the exception of its upper and lower boundaries, of course).

The hue of the ashen layer on the night side of the earth pales, about 2 to 3 minutes before the spacecraft leaves the shadow region, and a light blue aureole appears. It steadily becomes brighter and lighter above the horizon. A rosy band with reddish vertical "dashes" then appears above the edge of the horizon, in the supersolar region, quickly becoming a luminous oval which, later on, is seen as part of the sun's disk steadily rising above the horizon. Sunrise can be observed with the naked eye when seen with one-third of the sun's diameter above the horizon, after which there is the brilliant, blinding, light of direct solar rays.

The use of the layers of brightness, or of the upper boundary of the ashen airglow layer, as an artificial horizon requires a knowledge of their precise angular dimensions, and a determination of the altitude of the layer. Time of passage of some body through this layer can be used to calculate the thickness /1279 of the reference navigation layer. The original data for finding the altitude of this layer are the following present parameters of the spacecraft's orbit: the geographic coordinates of the subsatellite point; the time of the observation and the orbital altitude of the spacecraft; the equatorial and orbital coordinates of the body; the position of the spacecraft in orbit (revolution number, time, and longitude of the ascending node).

The spacecraft's orbital altitude, the geographic coordinates of the subsatellite point, and the spacecraft's position in orbit all were determined from ballistic data. The equatorial coordinates of the heavenly body were determined at the time of observation and were converted into orbital coordinates.

Measured during the flight of Soyuz 5 was the time of passage of the star Nath in $\beta$ Tauri (magnitude $m = 1.78$) through the ashen layer prior to sunrise (the sun was about $2^\circ$ below the horizon). The time was $t = 67$ seconds. The measurement was made on Soyuz 5's fifth revolution on 15 January 1969. The star was tangent to the layer and passed through it, setting below the earth's horizon at $16^h 53^m 17^s$ Moscow time.

The coordinates of the orbital pole were $\alpha_p^n = 140°$; $\delta_p^n = 38°36'$. The geographic coordinates at the time the β Tauri type star was observed were $\varphi = 51°S$ and $\lambda = 163°E$.

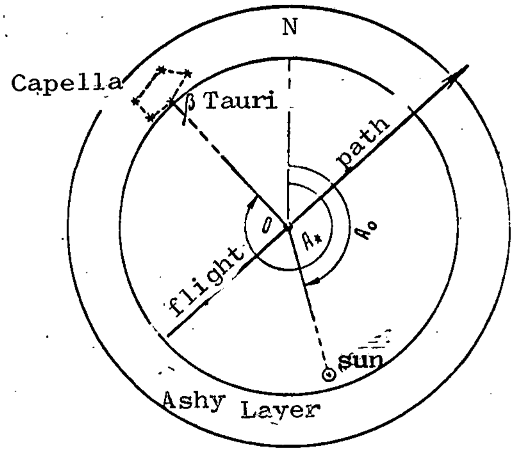


Figure 1. Location of the body in a horizontal system of coordinates. N - the north point; $A_{\odot}$ - the azimuth to the point of sunrise; $A_{\odot} = 166°$; $A_*$ - the azimuth of the star Nath (β Tauri), $A_* = 319°$.

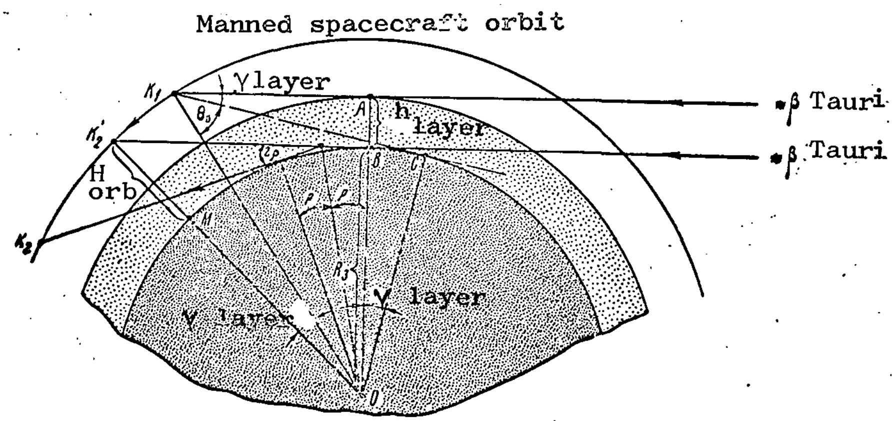


Figure 2. Schematic diagram of the determination of the altitude of the airglow layer.

The equatorial and orbital coordinates of the sun were $\alpha_{\odot} = 297°12'$; $\delta_{\odot} = -21°06'$; $\alpha'_{\odot} = +30°$; $\delta'_{\odot} = -63°$. The corresponding magnitudes for β Tauri equalled $\alpha_* = 81°05'$; $\delta_* = +28°35'$; $\alpha_*' = 172°$; $\delta_*' = +38°$. The orbital angular velocity of the Soyuz 5 spacecraft at the time of measurement was $\omega = 4.05$ degrees per minute.

We found the angular dimension of the airglow layer (Figure 2), with the orbital declination of the β Tauri type star ($\delta_*' = +38°$) taken into consideration (Figure 2), to be

$$\gamma_{\mathrm{layer}} = \omega t \cos \delta_*' = 3°34'. \quad (1)$$

Since the orbital altitude of the Soyuz 5 spacecraft at the time of the measurement was $H_{orb} = 253$ km, the angular dimension of the earth's radius (Figure 2) was /1280

$$\theta_0 = \arcsin \frac{R_e}{R_e + H_{orb}} = 74°07', \quad (2)$$

where

$R_e$ is the mean radius of the earth.

Taking Eqs. (1) and (2) into consideration, and using simple geometric relationships, we obtain the altitude of the airglow layer, $h_{layer}$, on the night side of the earth as

$$h_{layer} = [(R_e + H_{orb}) \sin (\theta_0 + \gamma_{layer})] - R_e \simeq 100 \text{ km}. \quad (3)$$

Refraction was disregarded in determining the altitude of the airglow layer through Eq. (3). We calculated the astonomical refraction by using a model of a layered spherical atmosphere, homogeneous in the horizontal direction, with standard vertical temperature, density, and pressure profiles [8]. The relationship between the angle of refraction, ρ, and the wavelength, λ, in the visible spectrum can be ignored [9].

Let us suppose that the angle of astronomical refraction at the level of the earth's horizon is $\rho = 35'21''$; that is, the total deviation of the sighting beam at the celestial horizon is $2\rho = 70'42''$ [10-11]. However, the star, upon passage through the ashy airglow layer, may not necessarily set at the earth's celestial horizon, but will be visually "extinguished" at some level above the horizon because of the scattering and absorption of the light in the lower layers of the atmosphere. In this case, the angle of astronomical refraction, and the total deviation of the sighting beam, will be smaller than at the level of the celestial horizon when the body is observed from space.

The thickness of the ashen airglow layer on the night side of the earth was computed as follows, using the data [11] on the angle of astronomical refraction, $\rho_*$ in terms of the altitude of the perigee of the line of sight, $h_0$

$$h_{layer} = (R_e + H_{orb}) \sin\left[\omega t \cos \delta'_* - 2\rho(h_0) + \arcsin \frac{R_e + h_0}{R_e + H_{orb}}\right] - R_3 \qquad (4)$$

Table 1 lists the results.

Table 1

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $h_0$, km | | 0 | 3 | 5 | 8 | 10 | 12 | 15 | 20 | 25 |
| $h_{layer}$ | (Soyuz 5) | 70.4 | 81.4 | 87.4 | 94 | 97.5 | 102.6 | 107.2 | 113.8 | 118.5 |
| $h_{layer}$ | (Soyuz 9) | 67.7 | 77.6 | 82.9 | 89.5 | 92.6 | 97.4 | 100.7 | 106.6 | 112.6 |

If it is accepted that the threshold contrast between the brightness of a β Tauri type star and that of the atmospheric background in the visible spectrum is at the 5 to 10 km level when the observation is made from an altitude of 250 km, the true thickness of the night layer is equal to $h_{layer} \simeq 85$ to 95 km. According to the data kindly furnished the authors by V. N. Sergeyevich, the brightness of a β Tauri type star observed from an altitude of $H_{orb}$ = 250 km has the threshold magnitude ($m \simeq 5 - 6$) for a standard model of the earth's mean atmosphere at altitude $h_0$ = 8 km. Consequently, and in accordance with Table 1 (Soyuz 5), the upper boundary of the ashy airglow layer on the night side of the earth should, as a mean, be located at an altitude of 94 km.

It should be pointed out that the phenomenon of the ashen airglow layer on the night side of the earth was observed before this [4-6]. Reference [7] contains a description of this phenomenon as a result of the flight of Soyuz 9 (January 1970). The thickness of the ashen airglow layer was determined by Soyuz 9 by measuring the time of passage of the planet Venus (magnitude m = -4.11) through this layer (t = 54.8 seconds, $h_{layer}$ = 94.8 km; influence of refraction not considered). The orbital altitude of Soyuz 9 at the time of measurement was $H_{orb}$ = 220 km. The orbital declination of Venus was small ($\delta_*' \sim 2°$), so /1281
reference [7] does not take it into consideration in the calculation of the

airglow layer thickness. The results of our calculation for the altitude of the upper boundary of the airglow layer, with refraction based on the data from the flight of Soyuz 9 taken into consideration, also are listed in Table 1.

The results of the independent determination of the altitude of the airglow layer by the Soyuz 5 and Soyuz 9 spacecraft indicate that the phenomenon of the airglow layer is stable in terms of time, does not depend on the geographic position of the observer, and has a fixed vertical scale. It is quite possible that the airglow layer phenomenon is the result of hydroxyl (OH) radiation under night conditions. Table 2 lists the results of rocket measurements [12-14] of the altitudes of OH airglow layers, which correspond to the thickness of the ashy airglow layer determined above. Spectrophotometry of the earth's night atmosphere in the airglow layer region from space will help explain the nature of the phenomenon described.

The advantage in using the observations of the phenomenon for purposes of autonomous navigation and orientation of spacecraft in near-earth orbits should be emphasized, because the cosmonaut [astronaut] can see quite sharply the edge of the airglow layer under the very definitely contrasting conditions of the night sky, and because of the absence of interference caused by the scattering of light in the earth's atmosphere, and in the layer itself.

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Table 2

| Source | Band of wavelengths ($\lambda$) and quantum jump | Geographic position | Time | Altitude of maximum glow, km | Width of radiation layer at half maximum of glow, km |
|---|---|---|---|---|---|
| [12] | 8305 - 8455 ($6 \to 2$) | 75°N | 10/26/69 | 95 | 15 |
| [13] | 7210 - 7450 ($8 \to 3$) | 32°N White Sands, New Mexico | 4/28/66 | 97 | 20 |
| [14]* | 7220 - 7370 ($8 \to 3$) | same | 11/6/59 | 90 | 15 |
| | 7400 - 10 200 | same | | 83 | 25 |

* Both measurements made on the same launch

REFERENCES


1. Gray, C., AIAA Paper, No. 869, (1969).

2. Kondrat'yev, K. Ya., Gal'tsev, A. P., Smoktiy, O. I., Khrunov, Ye. V., DAN, 191, No. 4, (1970).

3. Kondrat'yev, K. Ya., Volynov, B. V., Gal'tsev, A. P., Smoktiy, O. I., Khrunov, Ye. V., Izv. AN SSSR, ser. Fizika atmosfery i okeana, 6, No. 4, (1970).

4. Glenn, J. H., O'Keefe, J. A., Science, 136, No. 3522, (1962).

5. Manned Space Flight Experiments Symposium, Gemini Missions III and IV NASA, Washington, Oct. 18 - 19, 1965.

6. Foektistov, K. P., Rozenberg, G. V., et al. Sborn. Issledovanity kosmicheskogo prostranstva [In the collection: Space Research]. "Nauka" Press, 1965.

7. Kondrat'yev, K. Ya., Buznikov, A. A., Sevast'yanov, V. I., Smoktiy, O. I., DAN, 197, No. 3, (1971).

8. Blazhko, S. N., Kurs sfericheskoy astronomii [Course in Spherical Astronomy], 1954.

9. Rozenberg, G. V., Izv. AN SSSR, ser. geogr. i geofiz., 13, No. 5, (1949).

10. Allen, C. W., Astrofizicheskiye velichiny [Astrophysical Magnitudes]. Foreign Literature Press, 1960.

11. Link, F., Lunnyye zatmeniya [Lunar Eclipses]. Foreign Literature Press, 1962.

12. Harrison, A. W., Canad. J. Phys., 48, No. 19, 2231, (1970).

13. Baker, D. J., Waddoujs, R. O., J. Geophys. Res., 72, No. 19, 4881, (1967).

14. Packer, D. M., Ann. Geophys., 17, No. 1, 67, (1961).



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